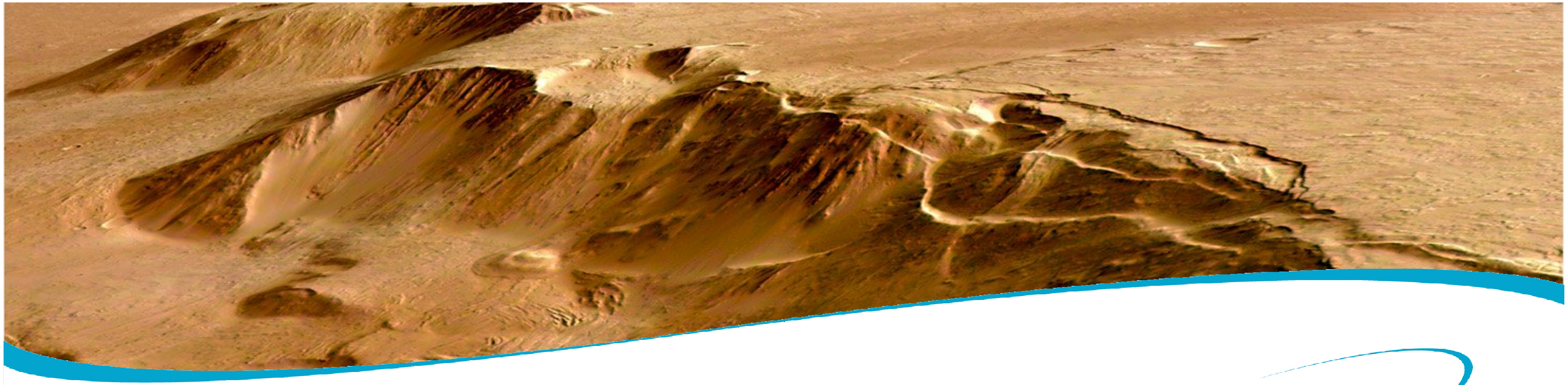

LANDING SITE TARGETING AND CONSTRAINTS FOR EXOMARS 2016 MISSION

Template reference : 100181708K-EN

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TAS-I BUOOS

IPPW7 - Barcelona, 14-18 June 2010

- Exomars 2016 and 2018 Missions
- Exomars 2016 Mission Components
- 2016 Mission outline
- EDL Key Facts
- EDL Constraints
  - Entry Corridor Constraints
  - Landing Site Constraints
- Landing Site Characterisation
  - Terrain characterization
  - Hazards identification
- Landing Site Certification
  - Hazard and Risk Maps
  - Compliance to constraints

2 Missions

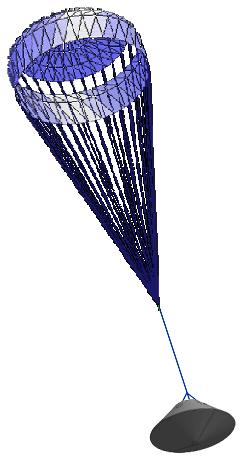
- **2016 Mission with ESA leadership**
- **2018 Mission with NASA leadership**

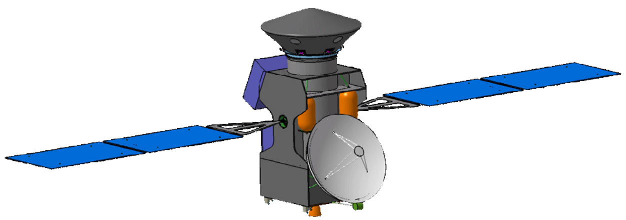
2016 Mission Objectives

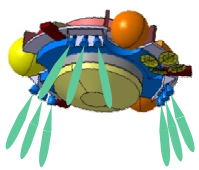
- Provide Europe with the required technologies for successful entry descent and landing of a payload on the surface of Mars
- Perform investigation on the Martian atmospheric trace gases and their sources
- Ensure communications capability for the 2018 rovers as well as any other international assets on the surface of Mars

2016 Mission Components

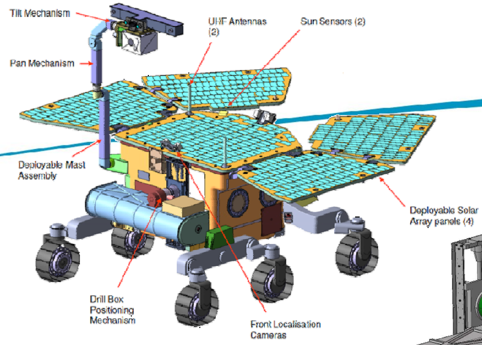
- ESA provided S/C Composite
  - Entry Descent & Landing Demonstrator Module (EDM)
  - Orbiter Module (OM)
- NASA provided Launch vehicle

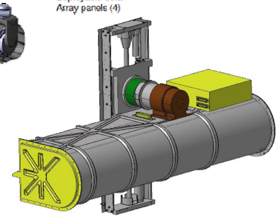


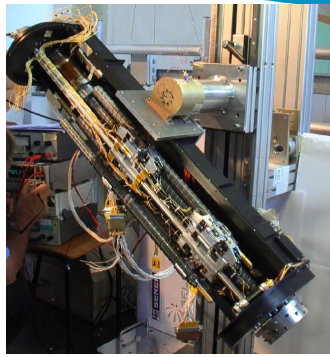




ExoMars 2018

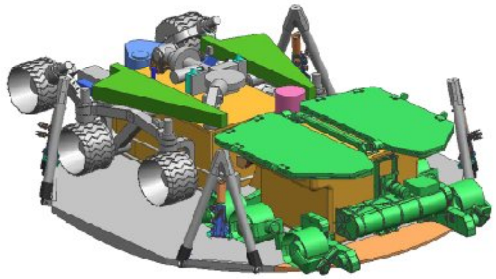






2018 Mission Objectives

- **Technology Demonstration**
  - Surface mobility with a Rover
  - Access to the sub-surface to acquire samples
  - Sample preparation and distribution for analyses by scientific instruments
- **Scientific Objectives**
  - To search for signs of past and present life on Mars
  - To investigate the water/geochemical environment as a function of depth in the shallow subsurface

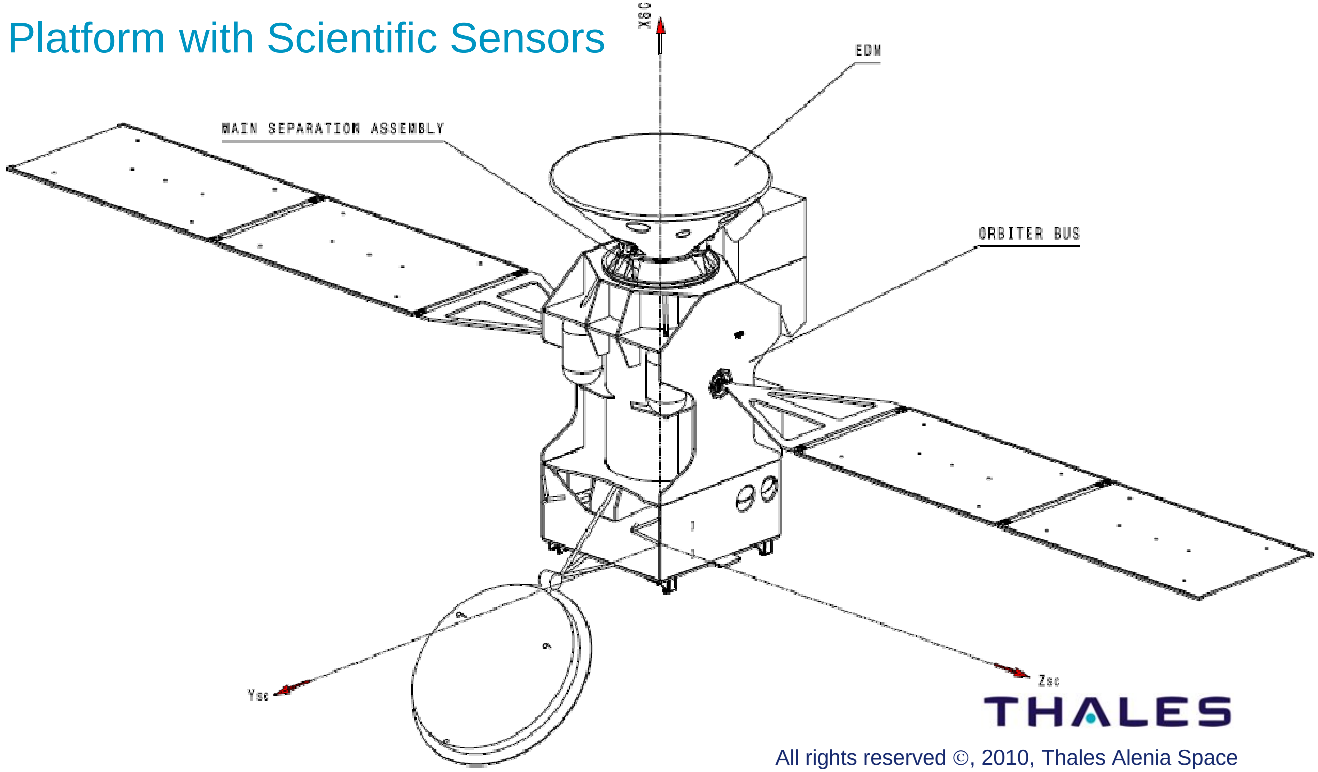


2018 Mission Components

- **NASA provided launch vehicle**
- **NASA provided EDL (MSL-like, sky crane)**
- **Rovers**
  - NASA Mars Astrobiology Explorer-Casher (MAX-C)
  - ESA ExoMars Rover (EXM-R)
- **ESA provided Rover Operation Control Centre (ROCC)**

2016 Spacecraft Composite – 4400 kg launch mass

- **Orbiter Module (OM) – 1365 kg**
  - Orbiter Bus and Orbital Scientific payload package of 125 kg
- **Main Separation Assembly (MSA)**
- **Entry Descent & Landing Demonstrator Module (EDM)**
  - 600 kg, 2.4m diameter EDM with EDL technology sensors
  - 280 kg Surface Platform with Scientific Sensors



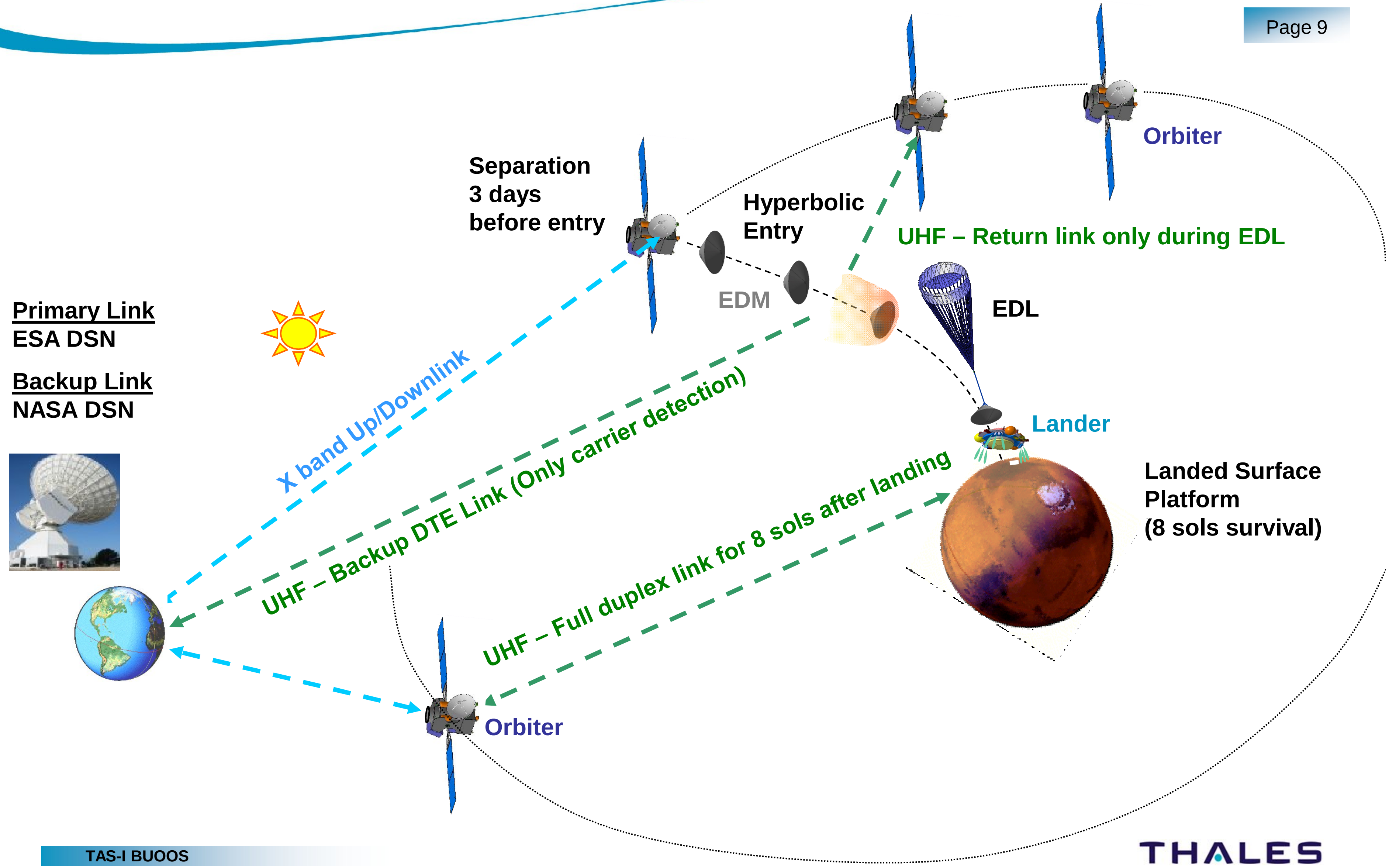
2016 Mission Phases (1)

Mission Phase	Events		Epoch	Notes
Launch		L	2016/01/07 ÷ 2016/01/27	American launcher vehicle, allocated 21-days launch window opening in January 2016
Early Operation Phase & Spacecraft Composite Checkout	– Sun acquisition and Power Generation – Deployment of High Gain Antenna – Telemetry Acquisition, stable attitude – Launch Injection Correction	LIC	L+7d	Complete spacecraft composite checkout including the science payload First Correction Manoeuvre for compensation of launcher injection errors
Interplanetary Cruise	– Trim Correction Manoeuvre 1 – Deep Space Manoeuvre (Part 1) – Deep Space Manoeuvre (Part 1) – Trim Correction Manoeuvre 2	TCM1 DSM1 DSM2 TCM2	LIC+10d L+130d DSM1+7d DSM2+10d	Type II transfer to Mars with duration of about 9 months Sizeable Deep Space Manoeuvre (DSM) to reduce ΔV for Mars Orbit Insertion (MOI), split in two parts Three Trim Correction Manoeuvres (TCM) during cruise to ensure appropriate targeting of the EDM to planned landing site in Meridiani Planum
Mars Approach	– Trim Correction Manoeuvre 3 – Trim Correction Manoeuvre 4	TCM3 TCM4	EIP-30d EIP-5d	B-plane fine targeting to Entry Interface Point (EIP) Fine targeting and last correction
EDM Separation	– Entry Attitude Acquisition – EDM Separation from OM	SEP	EIP-3d	Hyperbolic approach trajectory, direct entry Separation and stabilization spin rate provided by Main Separation Assembly
EDM Coast Phase Orbiter Retargeting Mars Orbit Insertion	– Orbiter Retargeting Manoeuvre – Mars Orbit Inertion	ORM MOI	SEP+12h ORM+60h 2016/10/19	3 days coasting phase with EDM hybernation Pericentre raising (Mars collision avoidance) and Mars Orbit Insertion MOI with active attitude control, thrust in the anti-V and maintaining communications link with the EDM Insertion to 4 SOL orbit, Solar Longitude 244°

2016 Mission Phases (2)

Mission Phase	Events		Epoch	Notes
EDM Entry Decent and Landing	– Ballistic Entry – Parachute Deployment – Front Shield Jettisoning – Radar Doppler/Altimeter activation – Radar Doppler/Altimeter operative – Back cover separation, RCS firing, Active braking – RCS off and free fall – Touch Down	EIP PAS FSJ RDAon RDAok SP-SEP TD	SEP+3d EIP+~180s PAS+20÷40S FSJ+10S TD-30s EIP+~180s	Spin stabilised entry, hyperbolic posigrade 118÷125° heading, 5.8÷6 km/s Deployment Mach 1.8÷2.1 RDA activation 6.5÷3.0km RDA ok 2.5 km. Terrain relative navigation and INS hybridisation Surface Platform separation and gravity-turn braking with PWM operated engines for simultaneous vertical and horizontal velocity cancellation and attitude control The Orbiter will perform continuous coverage of the EDM in order to receive the essential data related to EDL events for subsequent downloading to Earth.
EDM Surface Phase	– Orbiter 1st pass – Orbiter Period Adjustment Maneuvre – Orbiter 2ND pass		MOI+4sol MOI+4sol	First opportunity for EDL and science data collection Correction manoeuvre to adjust second pass Second pericentre after MOI; coverage guaranteed to receive EDL and science data
Mars Capture Orbit	– Inclination Change Manoeuvre – Apoapsis Lowering Manoeivre	ICM ALM	MOI+10sol MOI+12sol	Achievement of the 74° inclination for Science Orbit Insertion into 1-sol pre-aerobraking orbit
Aerobraking	– Waiting Phase – Aerobraking Walk-in, Main Phase, and Walk-out – Periapsis Raise Manoeuvre	 AB PRM	2016-11-1 2016-11-7	7 sol for Orbit determination, correction and manoeuvre planning Gradual periapsis lowering (~45 days), aerobraking operations, control of periapsis altitude vs aerothermal loads (80÷170 days), final reduction (~15 days) Circularization into final 400 km altitude, 74° inclination science orbit
Mars Orbital Science	– 1 Mars year (687 Earth days) of observations – Arrival of 2018 Rovers		2019-01-14	The science observations of the Orbiter will take place in this phase for about 1 Mars year. The period of the circular orbit will have to be chosen in order to ensure that the node drift is such that the EDL phase for the following Mars landing mission launched in 2018 is covered by the Orbiter
Mars Relay Phase	– Relay phase – Extended Mission End		2022-12-31	Along with other potential NASA Relay Orbiters such as MAVEN, MRO or Odyssey, the ESA EXM Orbiter will be available to provide data relay coverage to the ESA and NASA Mars surface mission launched in 2018 and whose current tentative arrival date to Mars is 2019-01-14

Communications

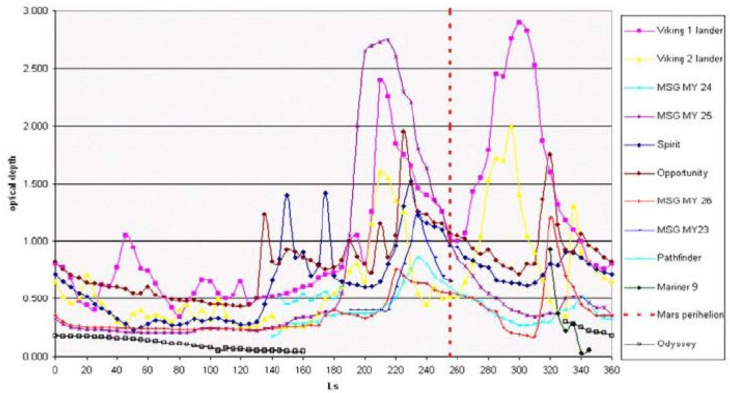


EDL key facts

- **Arrival at a fixed date (16-Oct-2016) during Dust Storm Season**
- **Direct entry from hyperbolic approach, prograde entry in daylight**
  - Hyperbolic excess velocity 3.256 to 3.463 km/s
- **Separation from OM oriented at EIP attitude with a Main Separation Mechanism providing both axial relative separation rate of 0.3 m/s and stabilization spin rate of 2.5 RPM at the same time**
- **Entry 3 days after arrival (19-Oct-2016)**
  - co-rotating entry velocities 5.70÷5.83 km/s
- **Deployment of a single parachute (Disk-Gap-Band Huyghens type)**
  - supersonic deployment and deceleration to subsonic terminal velocities
- **EDM sub-modules release strategy with a separation operated at Back Shell/Front Shield and at Backshell under parachute/Surface Platform**
- **RCS: 3 clusters of 3 PWM engines each, directly mounted on the landed Surface Platform**
- **Active deceleration strategy with g-turn maneuver**
- **Crushable structures for impact load attenuation**

EDL boundary conditions and constraints

- **Arrival at fixed date**
  - 19 Oct 2016, Dust Storm season (LS=244), but during Solsticial Pause
    - Optical depths less extreme than LS=190÷210 or 300 ÷ 340
- **Constrained targeting**
  - Optimised mission profile for compatibility with Meridiani area targeting, orbit plane change to 74° scientific orbit, aerobraking, circularization
  - Heading fixed to 118°÷125°
- **Challenges in landing ellipse**
  - Forced entry azimuth (heading)
  - Relevant atmospheric variability
  - Compliance with landing site morphology and design constraints to be guaranteed
  - Landing accuracy vs Entry Corridors



Event		LW Open	LW Close
Release	Epoch (UTC)	2016-10-16 15:48	2016-10-16 16:01
	Radius [km]	861723	913741
	Delta-V EDM [m/s]	0.251	0.253
	Delta-V Orb [m/s]	0.049	0.047
	SAA [deg]	107.23	104.73
	EAA [deg]	143.39	137.09
EDM Entry	Epoch (UTC)	2016-10-19 15:48	2016-10-19 16:01
	a [km]	-4039.56	-3571.38
	e	1.84465	1.95576
	i [deg]	27.19	34.05
	RAAN [deg]	316.80	320.84
	AOP [deg]	188.42	187.27
	True Anomaly [deg]	-17.49	-17.20
	Radius [km]	3517.515	3517.515
	Altitude [km]	120	120
	Longitude [deg]	-17.28	-16.57
	Latitude [deg]	4.13	5.54
	Relative Velocity [km/s]	5.69601	5.82781
	FPA [deg]	-11.80	-11.80
	Azimuth [deg]	118.06	125.03
	LST [hh:mm]	13:31	13:47
	SAA [deg]	105.80	103.45
	EAA [deg]	142.16	136.08
	Hyperbolic Velocity [km/s]	3.25611	3.46296
	Right ascension [deg]	-160.23	-156.83
	Declination [deg]	-24.59	-30.90

Exomars EDM vs MER

Data	Exomars EDM 2016	MER-B Opportunity
Entry date	19/10/2016	25/01/2004
Season	Late Summer	Winter
Landing site	Meridiani	Meridiani
Landing time (GST)	19-Oct-16 03:48 PM	25-Jan-04 04.55 AM
EIP Time (GST) (Entry beginning)	19-Oct-16 03:48 PM	25-Jan-04 04.45 AM
Mars Solar Longitude (LS)	244.7	338.99
Local True Solar Time (LTST) at entry	13:03	12:08:00
Local True Solar Time (LTST) at landing	14:22 - 14:35	13:23:00
Latitude at EIP	4.13N - 5.54N	4.1S
Longitude at EIP	17.3W - 16.6W	18.95W
Latitude at Landing	1.9S	-2.06N
Longitude at Landing	6.1W	354.01E
Landing Altitude /MOLA [km]	-1.44	-1.44
Entry type	posigrade	posigrade
Entry point [km]	121.5	125.92
Entry velocity (inertial) [m/s]	5912 - 6029	5720
Entry velocity (relative) (Co-Rotating) [m/s]	5663 - 5779	5480
Entry FPA (inertial) [deg]	Corridor	-11.47
Entry heading [deg]	118 - 125	83
Diameter [m]	2.4	2.65
Nose Radius [m]	0.6	0.66
Entry Mass [kg]	600	832.2
Ref Ballistic Factor [kg/m2]	77.86	88.88
Parachute diameter [m]	12	15.09
Parachute drag	0.4	0.4
Nominal parachute opening Mach	1.95	1.86
Nominal Parachute opening Dyn.P [Pa]	783	747
Nominal Parachute opening Altitude [km]	10.1	8.7
Nominal Parachute opening FPA	-22.8	-26.54
Heat Shield jettison time/parachute	40 s	20 s
HS jettison Mach	0.4	0.49
Peak Laminar heating (kW/m^2)	602	422
Total heat load (MJ/m^2)	36.87	27.1
Peak Deceleration	9.13g	6.4g

THALES

Entry Corridor Constraints

Parameter	Mild Constraint	Hard Constraint	Notes
Thermal Flux	<625 kW/m^2	<780 kW/m^2	Laminar heat flux constraint. Corresponds to turbulent overshoot below TPS qualification level of 2.07 MW/m^2
Thermal Load	<37.0 MJ/m^2	<42.3 MJ/m^2	Shallow limit Heat Load Constraint (current sizing estimate in dust storm scenario)
Deployment Mach	1.6<Mach<2.1	1.8<Mach<2.1	Highest triggering window within the consolidated Mach±0.15 uncertainty threshold from triggering algorithm performance
Altitude at Deployment / Verticalization	>6.7 km	>6.7 km	Estimate with constraints under 12 m Huyghens DGB parachute and allocated altitude losses and verticalization requirements Altitude losses allocation: - 1400 m for terminal braking with active RCS under 12 m DGB - 9.0 s for Radar Acquisition Phase - 5.0 s for GNC algorithms hybridization (INS+RDA) - 1.0 s for G-turn threshold detection - 2.0 s margin from back cover release and tip-off manoeuvre for g-turn active braking RDA requirements - 3000m±1000m: 55° off-vertical pointing - 2000m 35° max off-vertical pointing at 2000m
Load Factor	10.5g	12.2g	Extended steep entry case limit for the implementation of the hyperbolic entry and dust storm EDL Risk Mitigation Working Group recommendations
Inflation Force	65kN	69kN	Extended steep entry case limit for implementation of the hyperbolic and dust storm EDL Risk Mitigation Working Group recommendations.
Landing Accuracy	100 km target 120 km const.	100 km target 120 km const.	Target to be achieved while keeping 3 days coasting from separation to EIP 120 km constraint for landing area morphology with current arrival azimuth
Minimum entry corridor	1.0 deg	1.0 deg	Minimum entry corridor compatible with flight path angle accuracy at EIP

Slopes

Scale Length	Constraint	Rationale
2 to 10 km	Slope less that 3° on base-length of 2000m	Maximum error for radar slant range measurement. Radar may be activated in altitude range 3÷6.5 km, operated in closed loop below 2500 m (unambiguous altitude measurements via suitable PRF tuning
0.33 to 2 km		Bridging exponential self-affine model $C\Delta X^{(H-1)}$
330 m	Slope less than 8.6° on base-length of 330m	Ensure proper fuel consumption during powered descent
7 to 330		Bridging exponential self-affine model $C\Delta X^{(H-1)}$
<7m	Maximum relief 1.55 m down to maximum slope of 18°	Ensure proper altitude release error for engines shutdown and final impact on crushable structure

Thermal Inertia

- Thermal inertia > 150 J m^{-2} $s^{-0.5}$ K^{-1}
- Albedo < 0.28

Rock Abundance

Cumulative fractional area covered by rocks with diameter not larger than D

$F_k(D) = ke^{-q(k)D}$ $k = 0.069$, $q(k) = 1.79 + 0.152/k$

$H/D = 0.5$

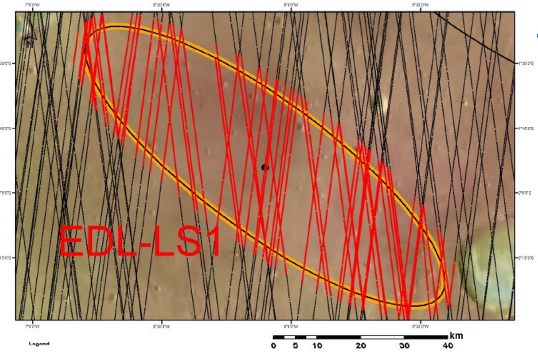
Radar Backscattering

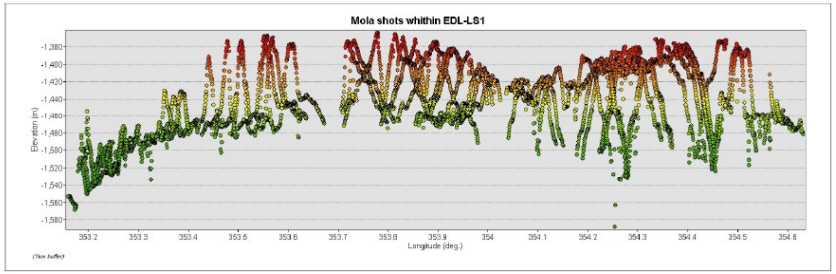
- Terrain Radar reflectivity > 0.07
- Backscatter cross section in Ka band (35 GHz)
  > -5 dB for nadir points, >-20dB for 80° off-nadir (Hagfors model)

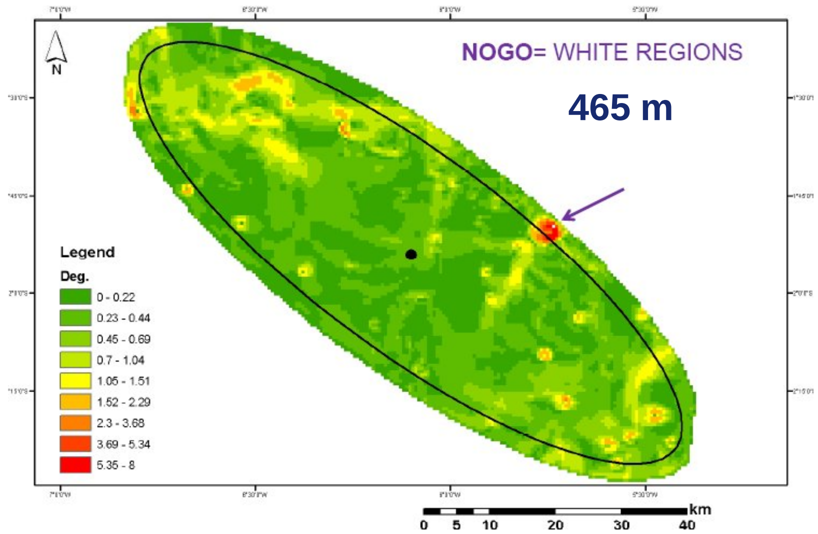
Slope Characterization

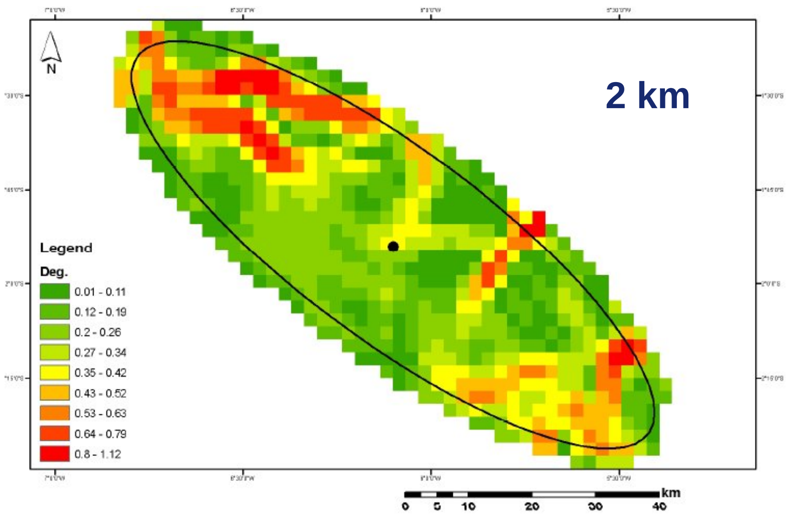
- **Slope constraints apply at kilometer (km), hectometer (hm) and meter (m) scale lengths**
- **Derivation of Digital Elevation Maps and Slope Maps from**
  - Mars Observer Laser Altimeter on Mars Global Surveyor (MGS/MOLA)
    - Resolution 463 m/pix
  - Mars Orbiter Camera on Mars Global Surveyor (MGS/MOC)
    - resolution >1.5 m/pix (3 m/pix typical).
  - High Resolution Stereo Camera on Mars Express (MeX/HRSC)
    - Level-4 products stereo images with 75m/pix resolution
  - High Resolution Imaging Science Experiment on Mars Reconnaissance Orbiter (MRO/HiRISE)
    - offers resolution >30 cm/pix (60 cm typical) allowing production of DEM's with 1 m resolution (~3 pixel).
- **Methods**
  - Bi-directional and a-direction slope determination from individual **altimetry profiles** (km-hm)
  - Digital Elevation Maps creation from **stereo images processing** and slope data extraction, where images are available (m)
  - **Photoclinometry** (0-D, 2-D), basically derived from MOC images (m-hm)
  - MOLA pulse-width at m scale
- **Approach followed for Exomars Phase B2**
  - MOLA (463 m/pix) or HRSC (75 m/pix) data for the km and hm scales
  - HiRISE/MOC/CTX (~1m/pix) for the metric scale

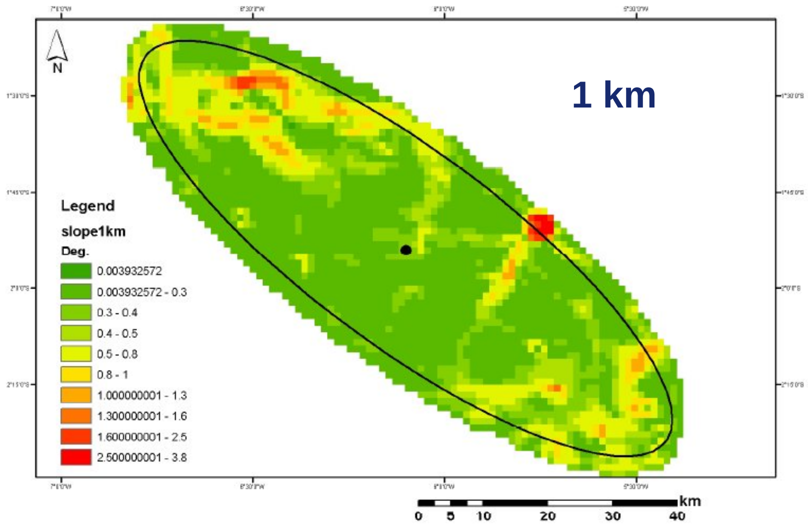
MOLA Shots in EDL-LS1 area



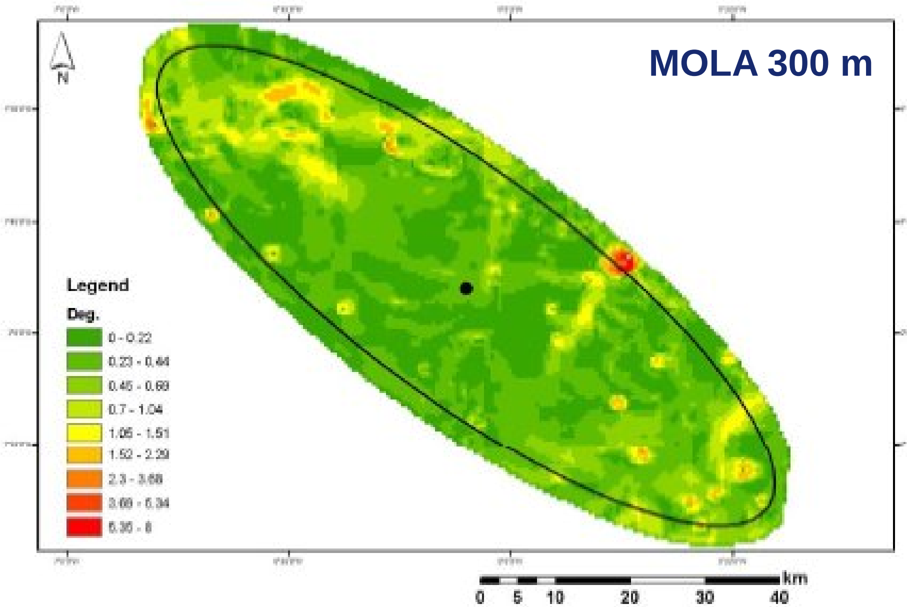


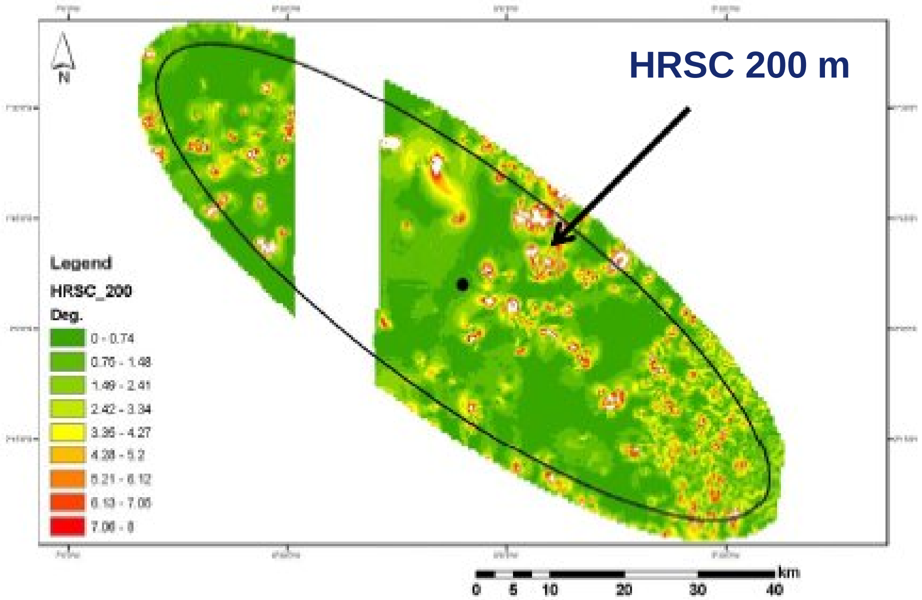






- **HRSC topography noisy in Meridiani**
  - due to the fact that the ellipse's area is rather featureless.
- **However 200-m-scale seems to essentially confirm that the slope is compliant at hectometer scale except for major (D > 1 km) craters**
- **Evaluations are underway to obtain more reliable DEM from HRSC data and to evaluate if the area encompassed by craters exceeds the 5% of the ellipse.**

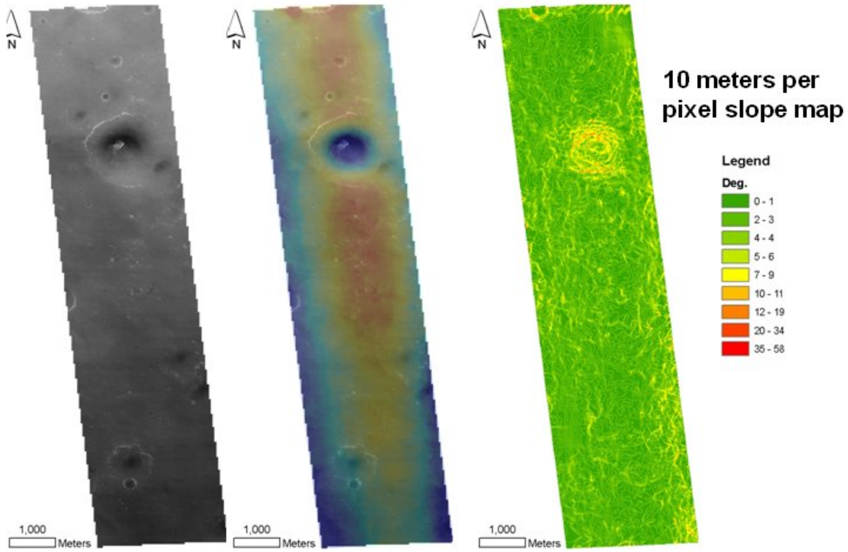


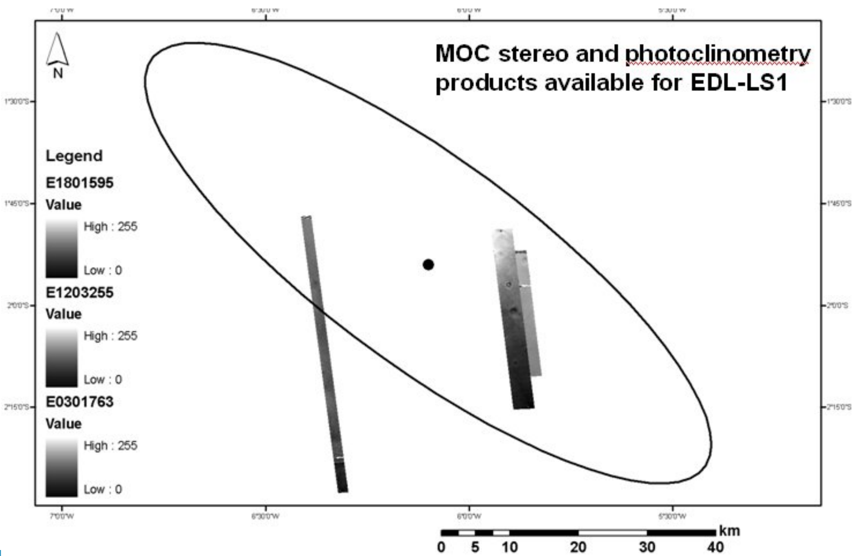


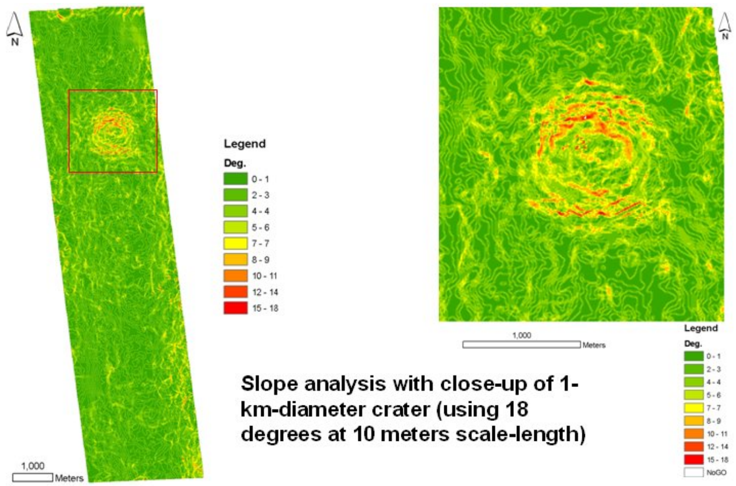
MOC Stereo and Photoclinometry

Limited Image Coverage

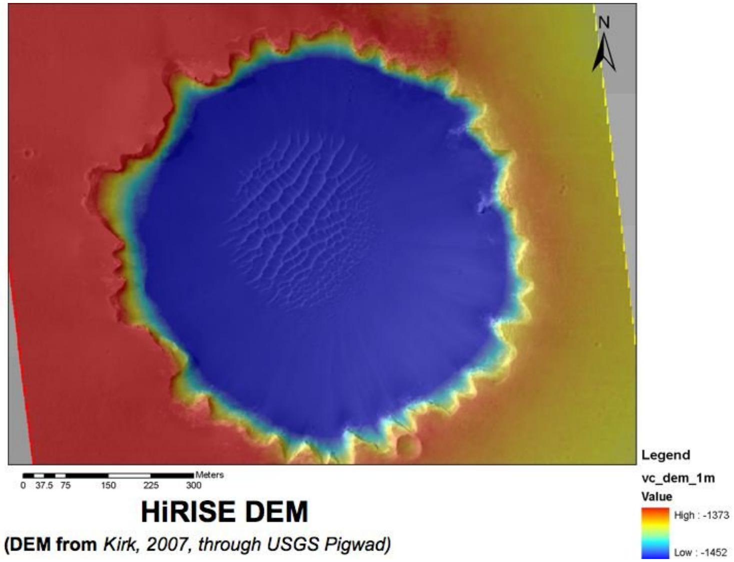
- **Twoset available**
  - 1 Stereo couple
  - 1Photoclino





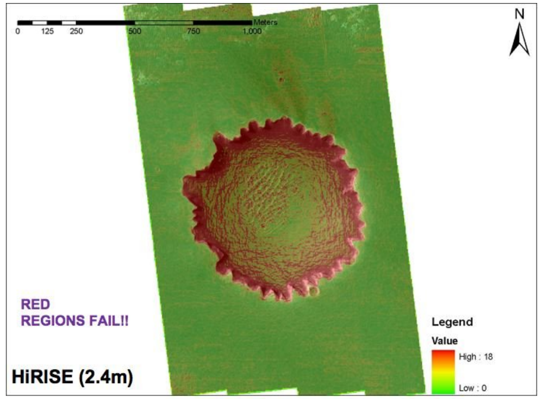


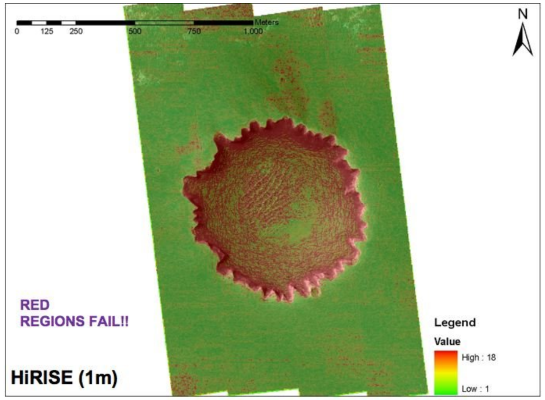
HiRISE Stereo

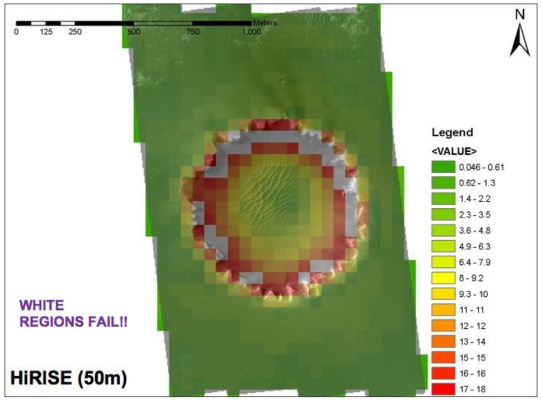


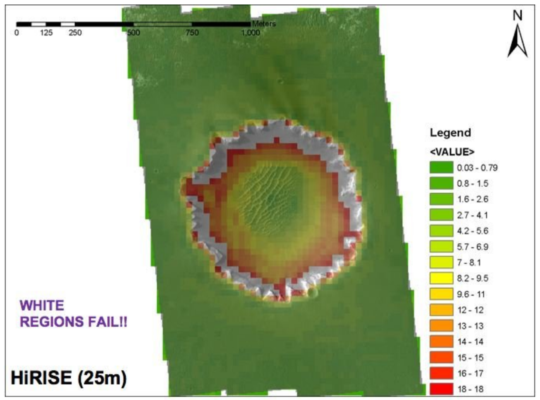
HiRISE DEM

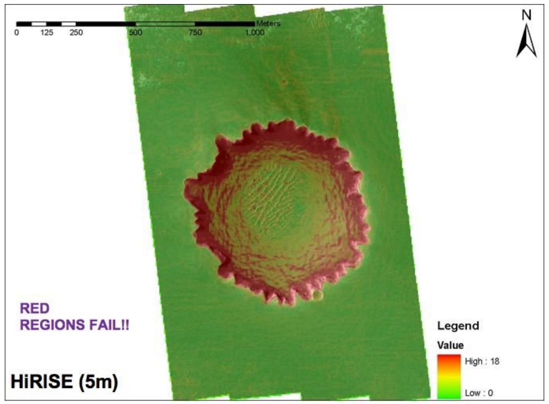
(DEM from ***Kirk, 2007, through USGS Pigwad)***







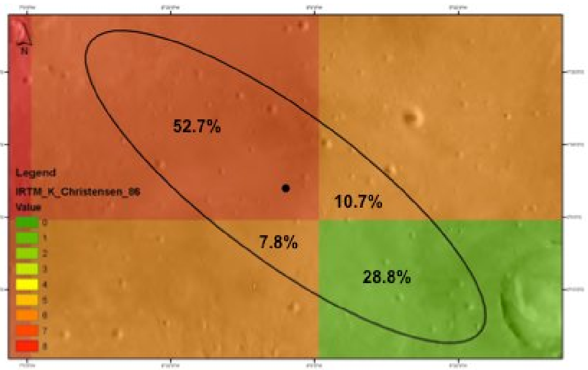


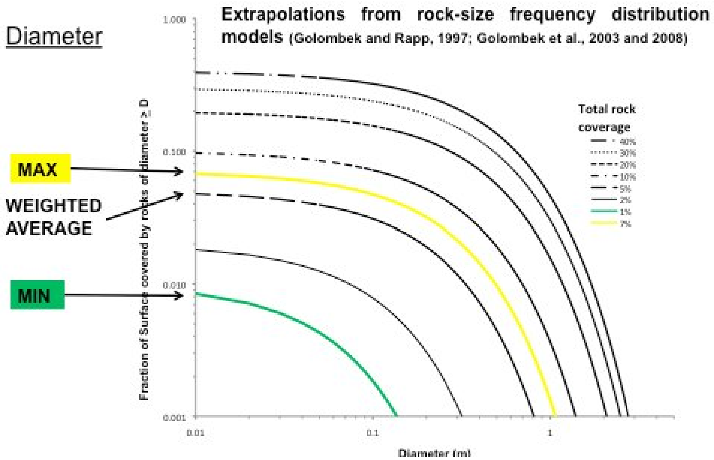


TAS-I BUOOS

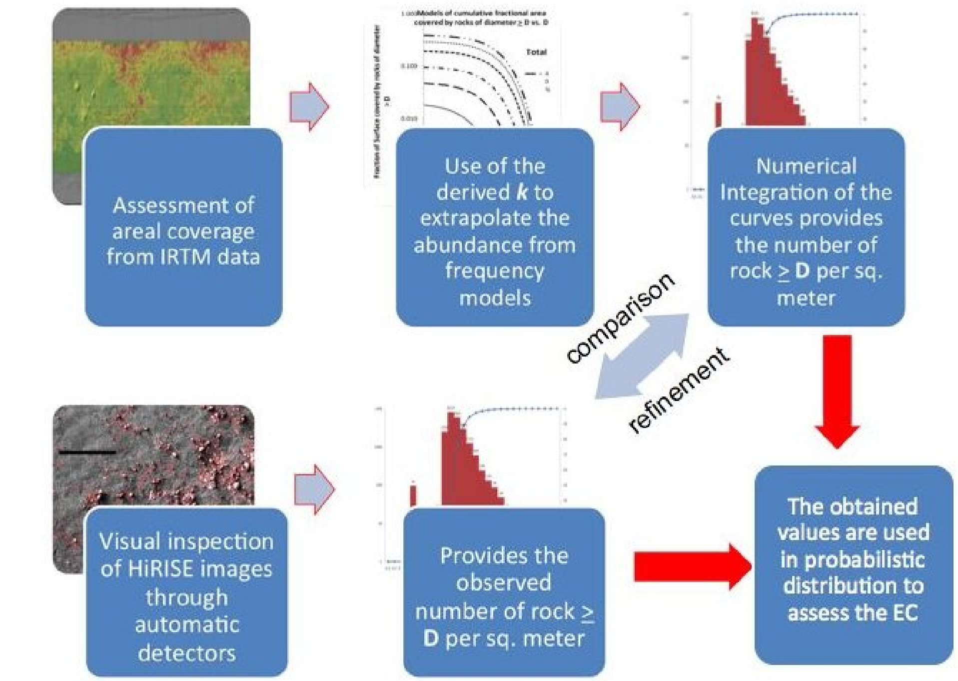
Rock distribution characterisation

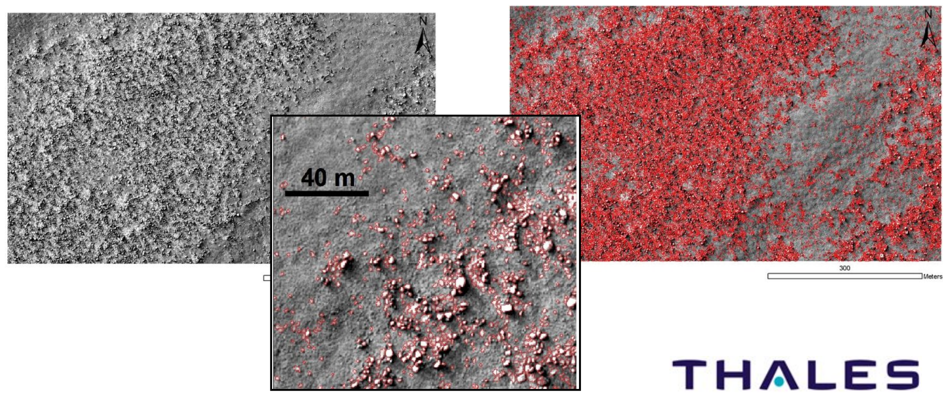
- **Viking InfraRed Thermal Mapper (IRTM)**
  - Coarse
- **Robotic Rock Detector**
  - Refinement from HiRISE images





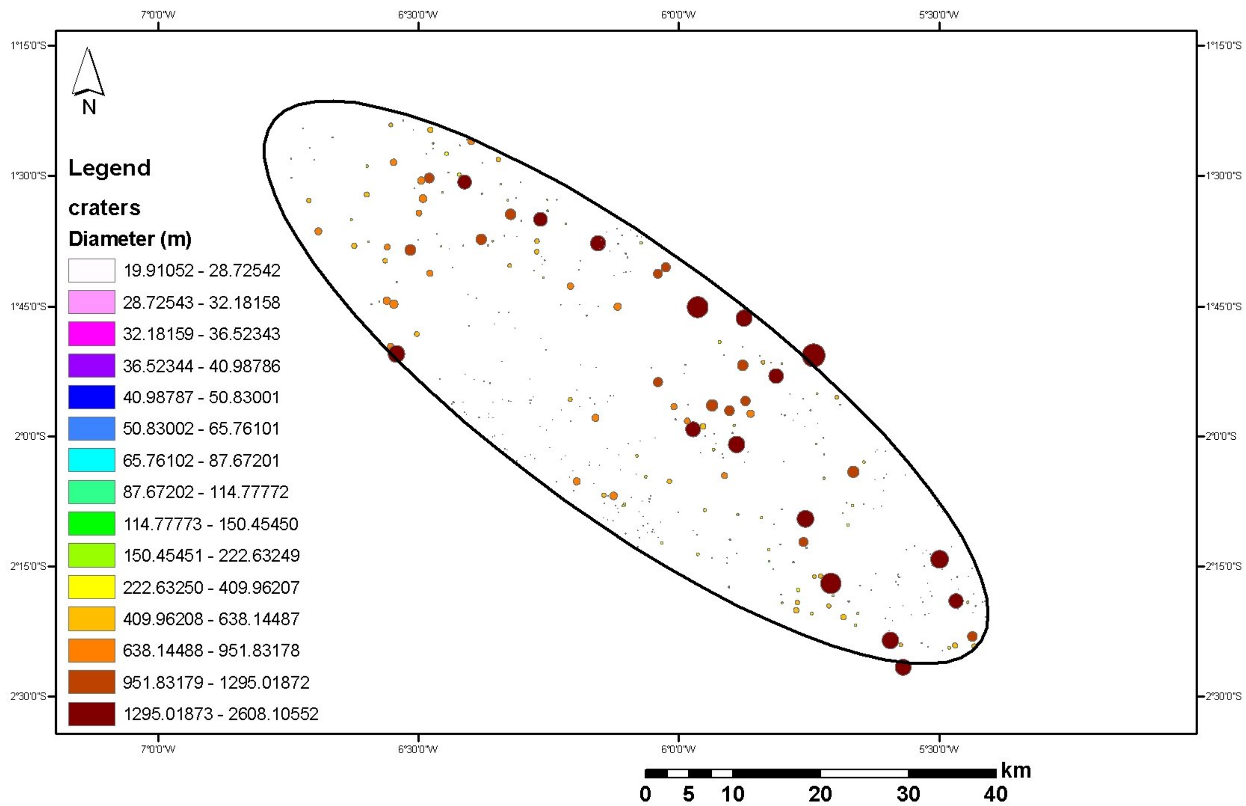
Rock distribution: work flow





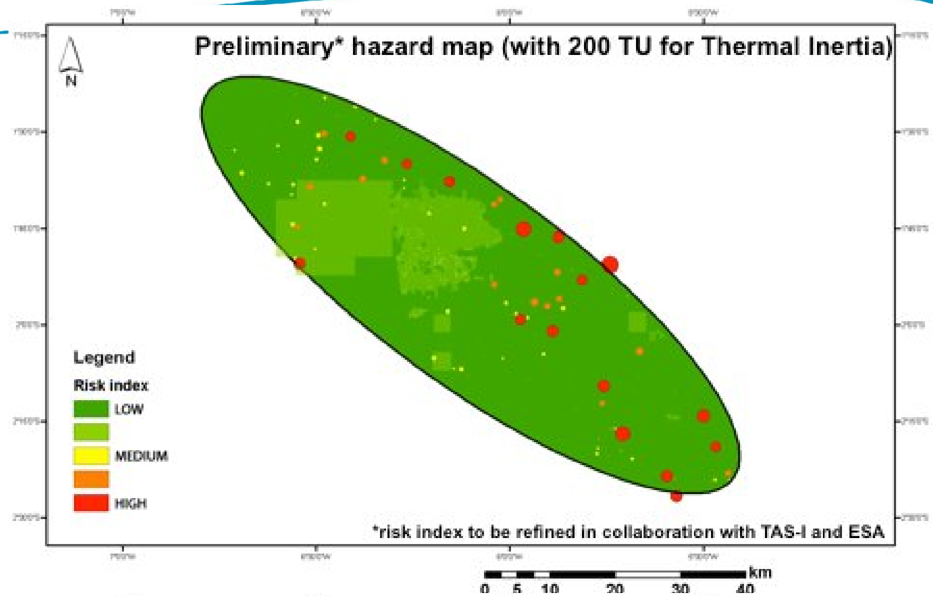
Hazard: Craters

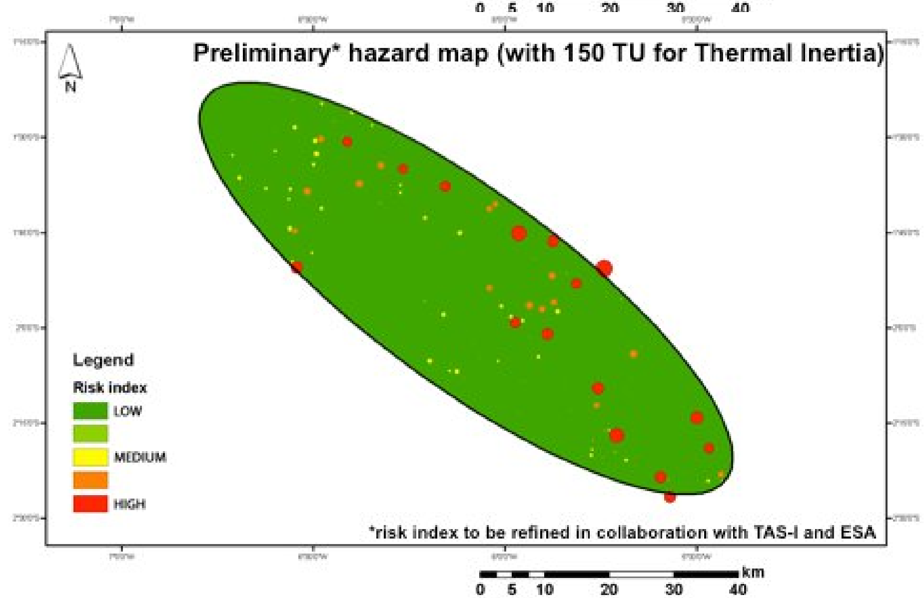
- **Craters as major hazard for EDL**
  - Craters (fresh, subdued) are the geomorphological features providing high risk for Descent and landing
  - 447 craters identified between 20 m and 2.6 km in EXM-EDL area



Hazard Maps

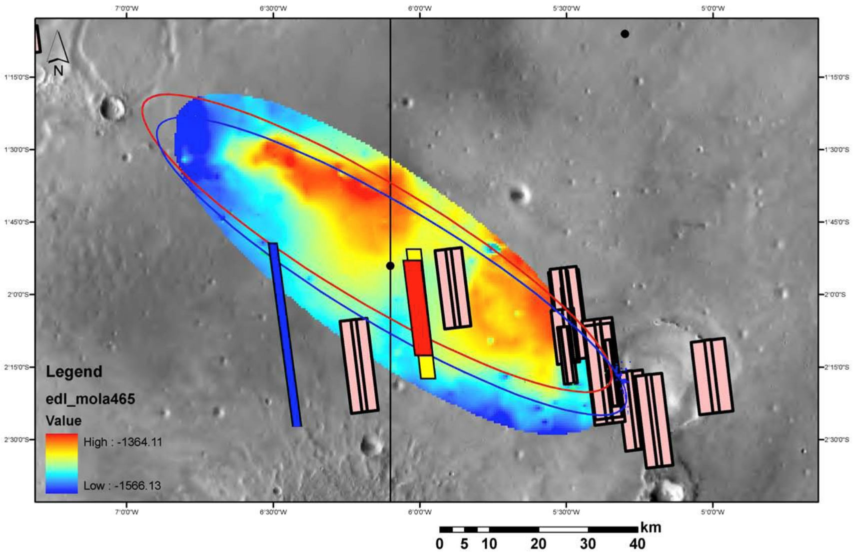
- Combined criteria to identify violation of constraints
- Criteria weights as per criticality of the constraint
- Need clever combination criteria to get quantitative risk maps
  - Work in progress
- Need to account for limited coverage

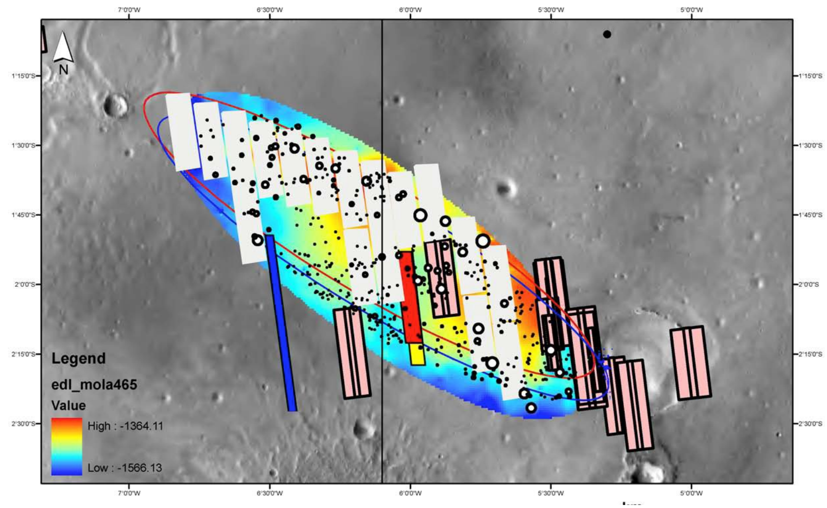


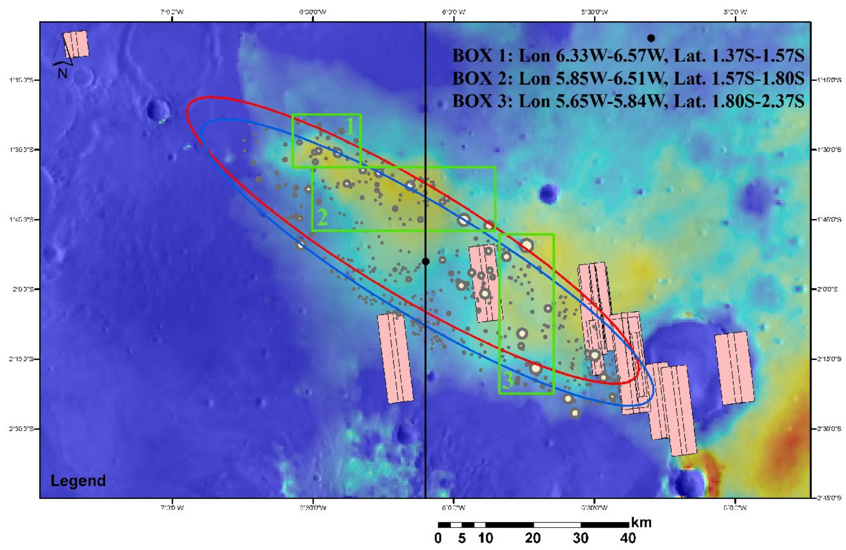


Current Imagery Coverage

- **MOC**
  - E0301763
  - USGS photoclinometry DEM, Stereo-pair E1203255-E1801595
- **HiRISE**







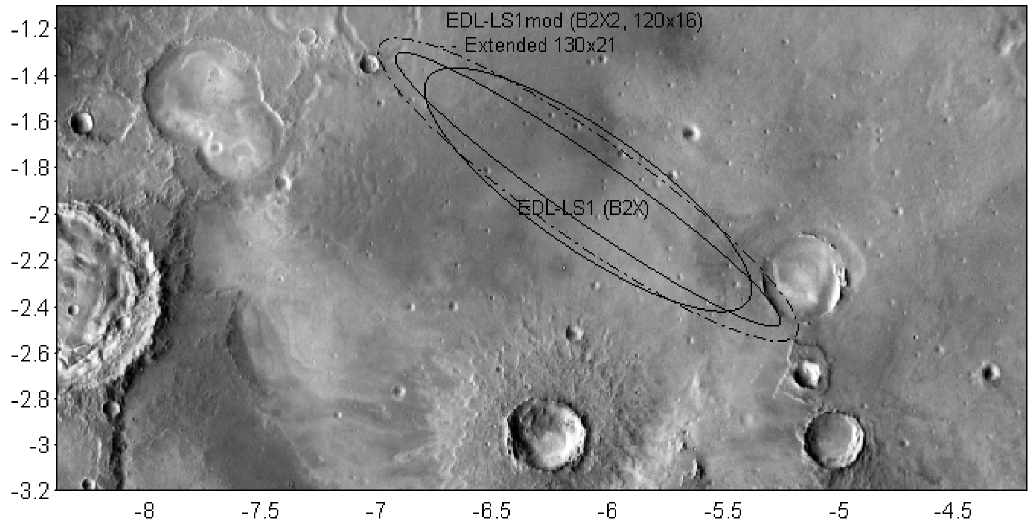
Additional Coverage required

- located in an area with high concentration of crater and ejecta (geomorphological features providing high risk for Descent and landing)

Conclusion (1)

- **No critical constraints identified so far**
  - Thermal inertia and albedo maps appear to be in line with engineering constraints
  - Slopes on the large scale hm÷km do not show relevant hazards
  - Close-up to 10 m scale put in evidence hazards close to crater rims slopes exceeding 18° (and up to 58°)
- **A limited number of MOC stereo images is available so-far.**
  - Photoclinometry has been used for processing, characterisation shall continue in order to identify risk rating based on crater distributions and fractional coverage of slope hazardous areas.
- **MOC stereo and photoclinometry products available for EDL-LS1 will be complemented in Phase B2X2, by additional HiRISE and HRSC processing**
- **Rock distribution from IRTM images led to the identification from thermal emission of rock abundance maxima up to k=0.069, which is within to Exomars specification.**
  - To be verified with Robotic Rock Detection
- **Preliminary assessment to be verified upon completion of characterisation**
- **Landing accuracy to be confirmed**

- The specific configuration of Exomars 2016 arrival, related to the need of harmonization between EDL targeting in Meridiani area, monitoring of EDL events   and acquisition of the final 74 degrees science orbit is posing some challenges for the landing ellipse.
- The azimuth of the landing ellipse ranging 118 to 125 degrees, as well as its extension, determines the need of imaging of the target landing area in order to prove the degree of compliance of the selected area to the engineering constraints that apply for successful EDL demonstration
- With current mission profiles, landing accuracy limit shall be kept to $\pm$50 km (3σ) downtrack to provide clearance wrt freash and subdued craters and related ejecta



Acknowledgments

- **The consortium led by TAS-I under ESA supervision is working to improve the capability in Europe to analyze, model and verify atmospheric and terrain characteristics relevant to the EDL performance**
- **The process of convergence of engineering constraints and characterization of the landing areas is in continuous evolution following the maturity of EDM design and the improvement in the characterization techniques, with the final target of providing a full certification of the suitability of primary (and back-up) landing sites for the fulfillment of Exomars 2016 EDM mission objectives**
- **Core Team**
  - ESA-European Space research and Technology Center (ESTEC)
  - Thales Alenia Space Italia (TAS-I)
    - Prime Contractor
  - Deimos Space (DMS-Spain)
    - Mission analyses
  - International Research School of Planetary Sciences (IRSPS-Italy)
    - Terrain characterization
  - Laboratoire de Météorologie Dynamique, Centre National de la Recherche Scientifique (LMD-France)
    - Atmospheric characterization

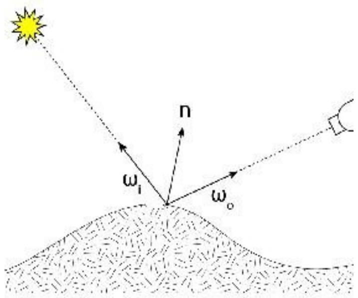
BACKUP SLIDES

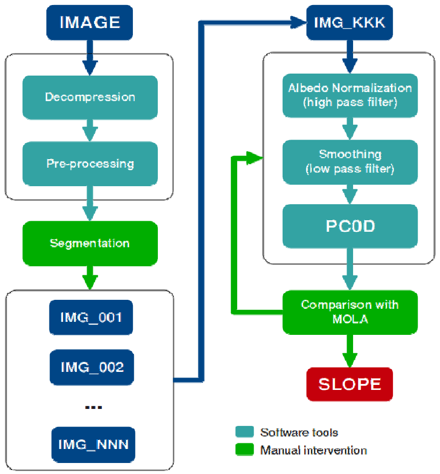
Photoclinometry (1)

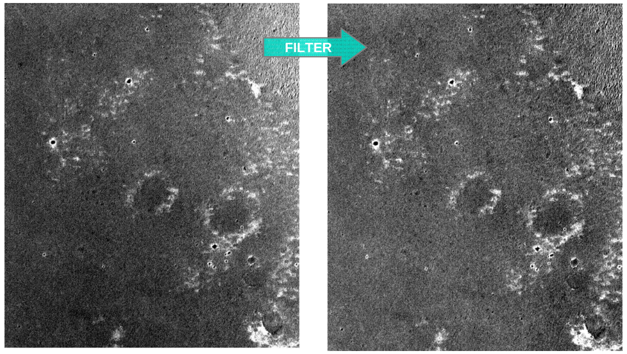
- **Photoclinometry (PC) or Shape From Shading (SFS)**
  - Infer surface topography brightness of an image
  - PC complimentary to stereo: single image used to produce slope maps and elevation models at image pixel resolution.
- **<u>0-dimensional PC</u>**
  - Computation of the local surface slope with respect to the areoid normal for each image pixel
  - Intrinsically generates a-directional slopes
- **<u>1-dimensional PC</u>**
  - Integrates the local slope along a given direction to produce an elevation profile.
- **<u>2-dimensional PC</u>**
  - Least square method to find DEM that match best the image brightness.
  - A-priori low resolution DEM required to get initial conditions for the least square algorithm and to fix the final DEM scale factor.
- **PC results sesitivity**
  - Sun position and S/C position and attitude.
  - Atmospheric scattering effects and haze.
  - Albedo variations
  - Image pre-filtering

Photoclinometry (2)

0D-Photoclinometry

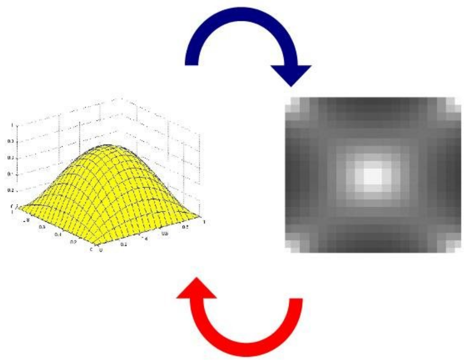




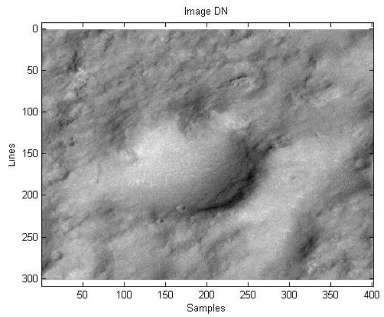


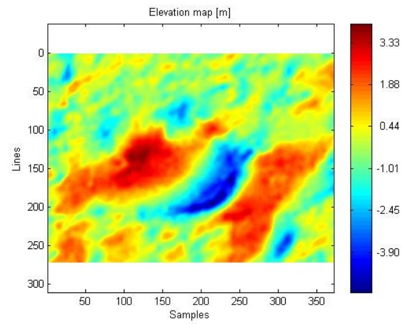
2D-Photoclinometry

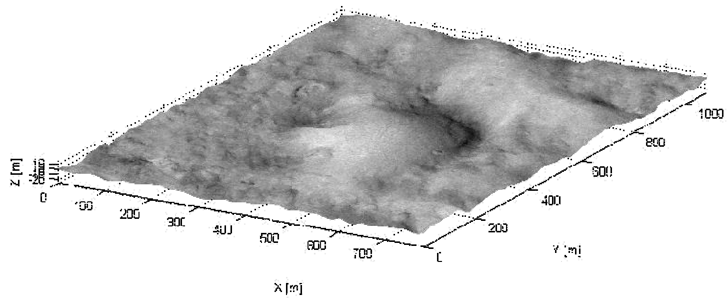
Rendering



Shape from shading

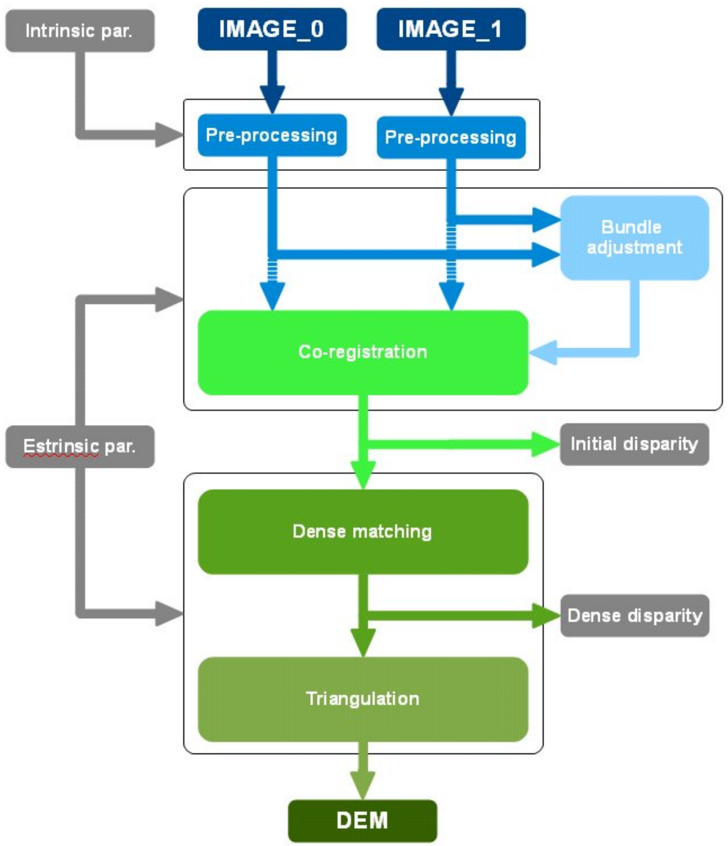






Stereo Photogrammetry

- **Stereo vision photogrammetry or StereoGrammetry (SG)**
  - DEM of imaged area at a resolution multiple of the original images
  - Triangulation procedure on recognised equivalent poi
  - Image preparation or pre-processing
    - decompression, radiometric calibration, optical distortioı compensation, ...)
  - Bundle adjustment
    - Constrain solution to tie points or MOLA shots
  - Alignment or co-registration
    - Correlation or dense matching (pixel-to-pixel)
  - Triangulation
    - 3D position of each point wrt reference frame.
  - Post processing
    - DEM creation, grid regularization, texture mapping, exp to GIS)
- **Ames Stereo Pipeline (ASP) used for Exomars**
- **Complex problem.**
  - depending from image quality, surface texture richnes and occlusions



Photoclinometry

- Single image
- Horisontal resolution at pixel level
- Measurement of integral slopes
  - Errors grow with baselength
- Radiometric
  - Artifacts with albedo variation
  - Scale error if haze not calibrated
  - No absolute heights

Stereo Photogrammetry

- Two convergent images
- Horizontal resolution ≥ 3 pixel
- Vertical resolution0.2 pix / (b/h)
  - Independent of baselength
- Geometric
  - Ignores albedo
  - Ignores atmosphere
  - Absolute heights require control

Prefer photoclinometry when

- Albedo variations not sominant
- Stereo fail to resolve elements
- Stereo matching/editig severe

Prefer stereo when

- Larger, more representative areasampled
- Photoclinometry is compromised by albedo variations

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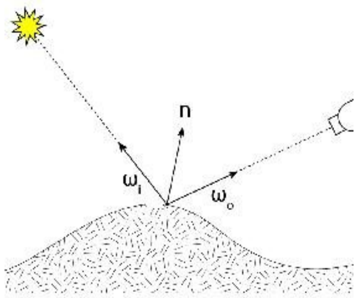
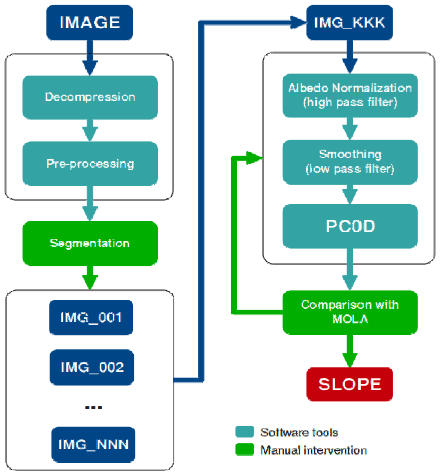
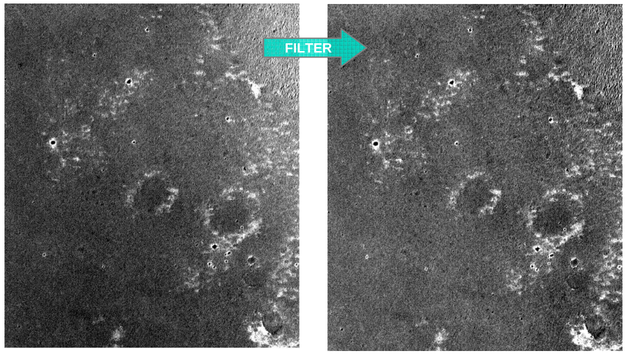
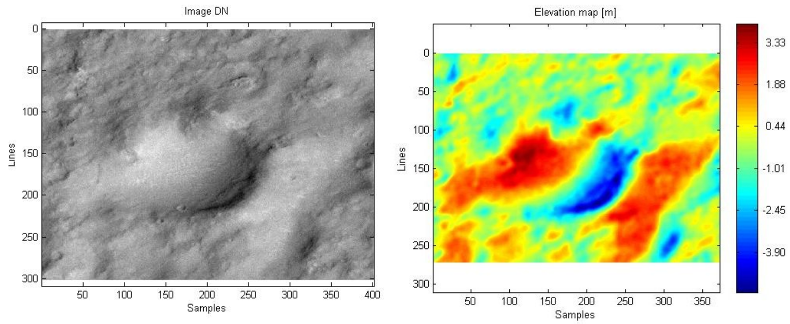
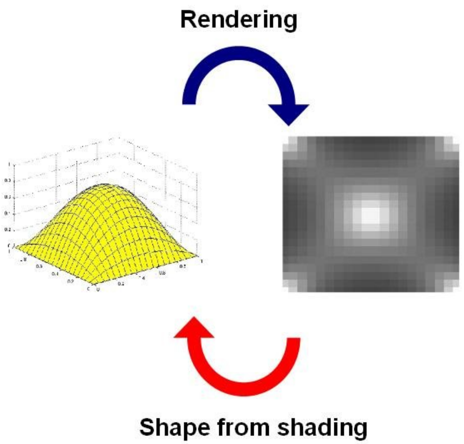


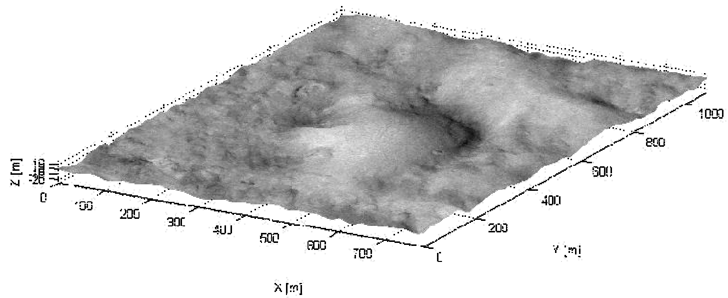






2D-Photoclinometry





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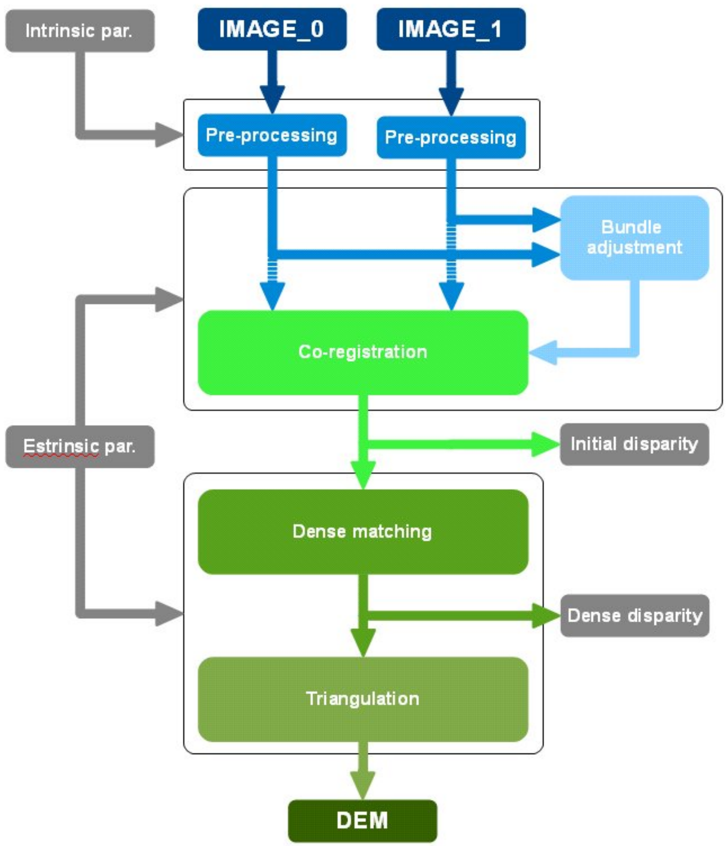

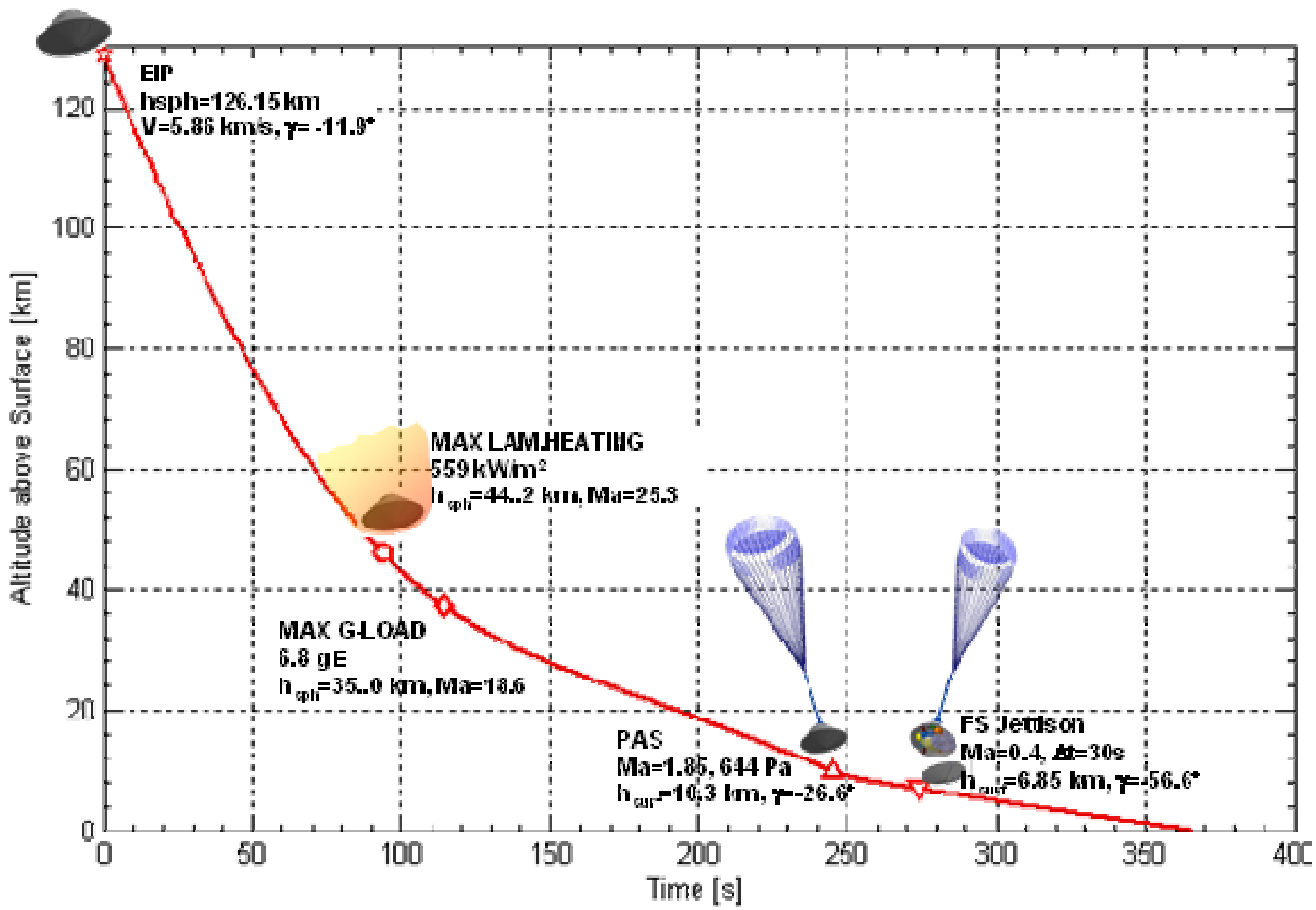
EIP
hsph=126.15km
V=5.86 km/s, γ= -11.9°
MAX LAM.HEATING
559 kW/m²
h sph=44..2 km, Ma=25.3
MAX G-LOAD
6.8 gE
h sph=35..0 km, Ma=18.6
PAS
Ma=1.85, 644 Pa
h sur=10.3 km, γ=-26.6°
FS Jettison
Ma=0.4, Δt=30s
h sur=6.85 km, γ=-56.6°
Altitude above Surface [km]
Time [s]
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400

Descent and Landing